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DEPARTMENT OF NATIONAL DEFENCE

DEFENCE RESEARCH ESTABLISHMENT OTTAWA

CONTRACTOR REPORT DREO/PSD/CPS - 51/86

EVALUATION OF VAPOURS FOR FACESEAL LEAKAGE TEST APPARATUS (U)

By

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CONTRACT NO. 14SV.97714-3-2541

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OCCUPATIONAL ENVIRONMENT
O E C
EVALUATION CONTROLS
Consultants Inc.

Our File No. 84-03/1

EVALUATION OF VAPOURS FOR FACESEAL LEAKAGE TEST APPARATUS

Study conducted by
OEEC Consultants Inc.

for

The Department of National Defence
Defence Research Establishment Ottawa
Bldg. 29, Shirley Bay
Ottawa, Ontario

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INTRODUCTION

Historically, the first respirators were used as a protection against particulate matter. This situation remained basically unchanged until the beginning of this century. The technology for manufacturing respirators offering reasonable protection against gases and/or vapours did not exist until the decade following 1920, mainly as the consequence and tragic experience of World War I. In the years following this period, most efforts were directed towards the improvement of the respirators' physical design and performance. However, no serious attention was paid to the quality of the respirator's face fit, its adequacy and resulting leakage, except for performing a crude negative-positive test after donning the respirator. Some attempts were made to develop testing methods by using a coal dust test, a talc test etc., as quantitative testing methods but with very limited success. Improvements were achieved in the development and use of qualitative methods by using some type of irritating smoke, banana oil or saccharin. However neither of the former can be universally used, due to some filtering media penetration by these substances.

The technological advances in the development and production of new chemical compounds and potential exposure to these materials during the last two decades changed dramatically the position and approach towards the quality control of respirators either during the production or their fitting before their use. In many countries specific standards are used to regulate the adequacy of design and/or maintenance of the quality during production [1-13].

The variety of facial features, the limited repertoire of

available respirators and the topological contours of the facepiece place restrictions upon the use of specific devices by an individual [14, 15]. The fundamental topic for assessment is that of respirator fit. A facepiece fit test is required to confirm, or predict, the performance of a given respirator on a specific individual [15].

A variety of fitting procedures have been commonly employed including visual assessment, pressure leak tests, Qualitative Fit Test (QLFT) utilizing agents with low odor threshold or irritating properties, and quantitative methods. The use of instrumental techniques for measuring the fraction of a test agent which penetrates into the space between the face and the respirator facepiece has been popularly described as a Quantitative Fit Test (QNFT) [16].

Although recognized for a long time, the problems associated with fit leakage were not approached with the thoroughness they deserve. Hence, there is a lack of equipment and instrumentation for testing leakage, specifically (face) fit leakage. None of the commercially available QNFT equipment offers the desired accuracy and sensitivity.

Several agents (challenging media) are presently employed in quantitative Face Fit Testing:

a) polydispersed, mechanically generated dioctyl-phthalate (DOP);

b) thermally generated DOP;

c) sodium chloride NaCl), and

d) corn oil (pharmaceutical grade).

The use of DEHP [di(2-ethyl hexyl)phthalate] has also been reported

[18].

Due to the concerns with DOP's carcinogenic properties its use has been curtailed in test a) and b) and the agent replaced with pharmaceutical grade corn oil, test d). The test corn oil aerosol generated by a particle generator has a mean mass aerodynamic particle diameter between 0.5-0.7 um. The detection electro-optical system is comprised of a forward light scattering photometer, dynamic linear amplifier and an integrated recorder. However, with this agent fungus growth may occur in the system, since the deposition of oil droplets on the walls of the testing chamber and the connecting hoses cannot be avoided and cleaning is rather difficult. Also, the oil's degradation with time gives an unpleasant smell. System c) is based on a thermally generated aerosol, using detection techniques and particle size clouds similar to those described above for corn oil although the actual particle size tends to be more uniform. However in either case, neither the uniformity of the particulate cloud nor the particle size distribution can be guaranteed with the certainty required to obtain very high fit factors. The inherent problems of electro-optical detection systems combined with those of particle generating systems and their sensitivity to supply electrical current voltage variation are cause for concern, thus the reason and need for the development of a more accurate and more sensitive fit testing method. Furthermore, these methods, being based on generation of particulate cloud and registration of particulate matter penetrating the leak, do not offer satisfactory answers to those concerned with high protection factors, specifically in cases where the challenging agent (contaminant) is of vapour or gas of

high toxicity.

For either aerosol or gaseous contaminants, there is a real need for a method and equipment capable of testing the seal to levels corresponding to 10^{-7} and preferably to 10^{-8}. This can be achieved only by using a gas or vapour as the challenging agent.

QUANTITATIVE FACE FIT TESTING PROTOCOL USING A GASEOUS CHALLENGE AGENT

The Quantitative Face Fit tests using a gaseous challenge agent will be conducted essentially as described elsewhere for this type of trial with the following changes. To satisfy the requirements for a method and equipment capable of testing the faceseal to the 10^{-7} - 10^{-8} level, it will be necessary to use the concentrations of the gaseous agent in the testing chamber of at least 1,000 ppm. Furthermore, the gaseous compound used as challenge agent must be detectable at concentrations less than 100 ppt. These conditions will have a major influence on the eventual choice of a challenge agent, thus the necessity for presenting these facts here prior to a discussion of the selection criteria for the gaseous agents.

SELECTION CRITERIA FOR GASEOUS CHALLENGING AGENTS

Selection Criteria

To satisfy all requirements placed on it by the QNFT test protocol presented earlier, an ideal gaseous challenging agent would meet the following criteria:

physico-chemical properties — The challenging agent should preferably be a chemically inert, low molecular weight gas that rapidly mixes with room air.

Background concentration — The natural concentration of the test agent in ambient air should be < 1 ppt.

Toxicity. — The gas or vapour should not elicit any acute toxic effect(s) following a short term (15 minute accidental exposure in test chamber) exposure to 1,000 ppm or less of the agent. Long term (8 hours) repetitive exposure of test operators to relatively low concentrations (<10 ppm) of the gaseous agent should likewise not produce adverse health effects. Its skin and/or occular absorption should be such that exhalation of the endogenously derived agent would not be evident during the first 15 minutes of the test. The gaseous agent should be commercially available at 99.9^{+}% purity with minimal content of toxic contaminants. It should also not be subject to thermal degradation which would produce

significant quantities of toxic products. Finally, the gaseous agent should have a relatively high Threshold Limit Value (TLV) and Short Term Exposure Limit (STEL) as established by the American Conference of Governmental Industrial Hygienists (ACGIH) [19].

Absorptivity — The gaseous agent should be totally absorbed by the charcoal in a face mask canister at test chamber concentrations of $\leq$ 1000 ppm for the duration of the test (at least 15 minutes).

Detectability — A non-sophisticated instrumental analysis of the gaseous agent should yield a signal giving a full scale recorder deflection at $\leq$ 100 ppt of the agent in air. The analysis of the gaseous agent should be relatively straight forward and free of interferences.

Stability — The gaseous agent must exhibit stability during long-term storage ($\leq$ 1 year).

Flammability — The gaseous agent should not be flammable.

Test Conditions — The gaseous agent should allow for an ease of generation of test atmospheres. It should also not absorb on material used to construct the test chamber or respirator and accessories.

PRELIMINARY SELECTION OF POTENTIAL CHALLENGING AGENTS

The most sensitive non-sophisticated instrumental analysis of organic vapours is accomplished today with a gas chromatograph (GC) equipped with an appropriate column and detector. Furthermore, halogenated hydrocarbons and halogenated gaseous inorganic compounds, of all available gaseous agents, are most easily analysed at the sub part per billion (ppb) level with a gas chromatograph equipped with an electron capture detector (ECD). We therefore limited our search for potential challenge agents for the QNFT test to these types of compounds.

Halogenated hydrocarbons are widely used in industry having found important uses as dielectrics, anesthetics, electrical insulators, refrigerants, propellants, organic solvents, and fire extinguishers and suppressants. The most commercially used compounds necessarily have properties which meet several of the selection criteria detailed earlier, that is, commercial availability, low cost, relative physiological inertness, chemical inertness, and non-flammability. The halocarbons of commercial interest have been categorized further as to most common usage as follows:

Halons: fire extinguishers, suppressants (Table 1).

Freons: refrigerants, propellants, solvents (Table 2).

Anesthetics: (Table 3).

The selection of potential candidates as challenging agents from amongst these many compounds is further facilitated if one adopts a generally accepted principle which relates chemical constitution with inherent toxicity by associating lower toxicity

TABLE 1: FLUORINE-CONTAINING HALONS

HALON		MOLECULAR WEIGHT	BOILING POINT °C
HALON 1202	Dibromodifluoromethane[1]	210	22.8
HALON 1211	Bromochlorodifluoromethane	165	-4.0
HALON 1301	Bromotrifluoromethane[2]	149	-58.0
HALON 2402	Dibromotetrafluoroethane	260	47.2

1 TLV (ACGIH) 100 ppm

2 TLV (ACGIH) 1,000 ppm

TABLE 2: FLUORINE-CONTAINING FREONS

FREON	MOLECULAR WEIGHT	BOILING POINT °C	TLV (ACGIH) (ppm)
Freon 11 trichlorofluoromethane	134.7	23.8	c 1000
Freon 12 dichlorofluoromethane	120.9	-29.8	1000
Freon 13 chlorotrifluoromethane	104.5	-81.4	--
Freon 21 dichlorofluoromethane	103	8.9	10
Freon 22 chlorodifluoromethane	86.5	-40.8	1000
Freon 23 trifluoromethane	70	-82	--
Freon 112 tetrachlorodifluoroethane	203.8	92.8	500
Freon 113 trichlorotrifluoroethane	187	47.6	1000
Freon 114 dichlorotetrafluoroethane	171	3.6	1000
Freon 115 chloropentafluoroethane	155	-38.7	1000
Freon 116 hexafluoroethane	138	--	--
Freon 142b chlorodifluoroethane	100.5	-9.5	--
Freon C-318 octafluorocyclobutane	200	-5.8	

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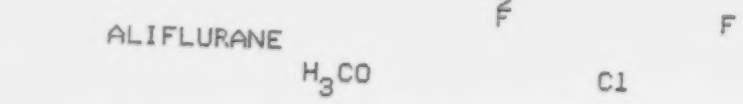
TABLE 3: FLUORINE-CONTAINING INHALATION ANESTHETICS

	MOLECULAR WEIGHT	BOILING POINT °C
HALOTHANE (fluothane) $CF_3CHClBr$	198	50
FLUOROXENE (fluomar) $CF_3CH_2OCH{=}CH$	95	
ENFLURANE (ethrane) CHF_2OCF_2CHFCl	134	
METHOXYFLURANE (penthrane) $CH_3OCF_2CHCl_2$	145	
ISOFLURANE (FORANE) $CHF_2OCHClCF_3$	134	
ALIFLURANE 	138	

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with an increasing number of fluorine atoms in the molecule (Clayton, 1966 [20]). Thus, the following five compounds were the results of a preliminary selection made amongst the most commonly used compounds from each category named above based on this principle.

Halon 1301 - trifluorobromomethane

Freon 12 - dichlorodifluoromethane

Freon 116 - hexafluoroethane

Freon C-318 - octofluorocyclobutane

Halothane - trifluorochlorobromoethane

In addition, sulphur hexafluoride (SF_6), a commonly used electrical insulating gas and ventilation system and environmental tracer gas was added to the list as it has many of the properties common to the other five choices.

A detailed consideration of each candidate gas on the basis of the criteria elaborated earlier follows.

TOXICOLOGICAL PROFILE OF CANDIDATE GASES OR VAPOURS

Some of the factors of importance in considering a potential intoxication of either the test subject or the investigator by the candidate gases or vapours are:

- the quantity of the individual test gas or vapour to which either subject are exposed;
- the duration of the exposure;
- the route(s) of absorption;
- the presence of toxic contaminants in the test substance or their generation through degradation [eg.thermal].

The relative importance of each of these factors during the performance of QNFT seal tests will be considered in turn in what follows.

Duration and Extent of Exposure

One of the primary concerns during the performance of QNFT tests would be with an accidental exposure of the test subject to elevated concentrations of either the test gas or vapour [1,000 ppm or less] for short periods [15 minutes or less] that is an acute exposure . A lesser concern would be with the exposure of the person or persons conducting the test to relatively smaller concentrations of the test substance [1 ppm or less] for relatively longer periods [full workday] for weeks at a time that is,chronic exposure. Although both occurences will be considered ,special attention will be given to the more likely acute intoxication by these gases or vapours.

Route(s) of Absorption

The most important route of absorption during faceseal tests would expectedly be inhalation. Skin absorption for most, if not all the candidate gases or vapours, would be of considerably lesser importance intoxication-wise albeit, of great importance for the QNFT test.

Toxic Contaminants

The existence of toxic contaminants in commercial preparations, individual candidate gases or vapours or their generation by degradation, especially thermal, will be considered. The toxicity of these substances will also be examined.

A toxicological profile of each candidate gas or vapour incorporating the aspects discussed above will be presented in what follows.

Halon 1301 (Bromotrifluoromethane)

As a group, Halons have the chemical and physical properties expected of effective fire extinguishing agents (Table 4) that do not corrode, react or contaminate the environment into which they are released. By virtue of their low reactivity and extinguishment ability in the gaseous state, they can protect the contents of a conflagration and are particularly effective where clean agents are required; where there are live electrical or electronic circuitry; for flammable liquids or gases; for surface burning flammable materials. Halon 1301 is considered the most useful and attractive of these fire extinguishing agents because of its high liquid

TABLE 4: PHYSICAL PROPERTIES OF SELECTED HALOGENATED HYDROCARBON FIRE EXTINGUISHING AGENTS

	HALON NO.	MOLECULE WEIGHT	APPROX. BOILING POINT °F	SPECIFIC GRAVITY OF LIQUID 68 °F	STORAGE THERMAL STABILITY °F
CARBON TETRACHLORIDE	1040	154	170	1.595	400
METHYL BROMIDE	1001	95	38	1.73	---
BROMOCHLOROMETHANE	1011	129	153	1.93	250
DIBROMODIFLUOREMETHANE	1202	210	73	2.28	350
BROMOCHLORODIFLUOROMETHANE	1211	165	25	1.83	400
BROMOTRIFLUOROMETHANE	1301	149	-72	1.57	<500
1,2 DIBROMOTETRAFLUOROETHANE	2402	260	117	2.17	<500

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density, low boiling point, low reactivity and relatively low toxicity .

The great majority of Halon 1301 fire extinguishing systems used in Canada and elsewhere today are of the "total flooding" type. This type of system is one which develops a uniform extinguishing concentration of agent (4-7%) [21] throughout an enclosure such as a room. It is capable of extinguishing a fire within the enclosure yet will maintain an atmosphere capable of sustaining life. However, it should be noted that the use of Halon 1301 in confined spaces is not currently recommended where such spaces are occupied or where evacuation cannot be achieved within five minutes [22].

1. Acute exposure

Initial studies [23-25] were conducted in the 1950's to determine the potential lethal concentration of the Halons. A variety of animal species (rats, guinea pigs, rabbits) were exposed to various concentrations of Halon gases for specific lengths of time. Results of one such study conducted with rats exposed for 15 minutes to Halon vapour are shown in Table 5, [21, 23]. In all cases, death was attributed to pulmonary oedema and hemorrhage. It is notable that the relatively elevated ALC for Halon 1301, 832,000 ppm (83.2% vol/vol) is indicative of this substance's inherently low toxicity for short-term exposure. Exposure of rats to 20% Halon 1301 for up to two hours produced no significant toxic effects. This result has led the Underwriter's laboratories to place Halon 1301 in the least toxic, class 6 category. This rating is still in effect.

TABLE 5: APPROXIMATE LETHAL CONCENTRATIONS (RATS) FOR 15-MINUTE EXPOSURE TO VAPOURS OF VARIOUS HALONS

AGENT	FORMULA	HALON NO.	APPROPRIATE LETHAL CONCENTRATION ALC ppm)
CARBON TETRACHLORIDE	CCl_4	104	28,000
METHYL BROMIDE	CH_3Br	1001	5,900
BROMOCHLOROMETHANE	CH_2ClBr	1011	65,000
DIBROMODIFLUOROMETHANE	CF_2Br_2	1202	54,000
BROMOCHLORODIFLUOROMETHANE	CF_2ClBr	1211	324,000
BROMOTRIFUOROMETHANE	CF_3Br	1301	832,000
1,2 DIBROMOTETRAFLUOROMETHANE	BrF_2CCBrF_2	2402	126,000

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Information on the effects of Halon 1301 on the central nervous (CNS) and cardiovascular systems have been obtained from studies of the sublethal effects of this gas [23]. Thus, it was found that exposure of various animal species to 10-18% vol/vol Halon 1301 and a 20% oxygen supplement was not lethal. However, a variety of CNS/behavioural effects ranging from depression to stimulation were noted depending on the species and concentrations used. Cardiac arrhythmias were observed at relatively high concentrations.

Cardiovascular changes produced by Halon 1301 resulting from CNS disturbances include hypotension [26], auroventricular arrhythmias [23, 24] and increased sensitivity of the heart muscle to catecholines (adrenaline, epinephrine) [23, 24, 27, 28]. The phenomenon of cardiac sensitization has been studied by stressing the test animals either by fright [23] or exercise [27] to increase the endogenous level of adrenaline or by injecting known amounts of adrenaline during exposure. A summary of the results are presented in Table 6. It is noteworthy that large doses of exogenous adrenaline-produced arrhythmias and ventricular fibrillation at relatively low (10%) exposures to Halon 1301. However, to date, similar results have not been obtained with concomitant exposure to similar levels of Halon 1301 and elevated endogenous adrenaline levels.

The dynamics of retention and clearance for Halon 1301 are shown in Figure 1. Thus, blood Halon 1301 levels plateau following continued exposure to the same concentration of this agent and remain at this level until exposure ceases. Thereafter, Halon is rapidly cleared from the blood - $t_{1/2}$ - 2 minutes for dogs [26].

TABLE 6: SUMMARY OF CARDIAC SENSITIZATION STUDIES FOR HALON 1301

Halon (%)	Test Animal	Adrenaline (mg/kg) body weight	Fatalities	Without Adrenaline	with Adrenaline	Adrenaline	Halon	CN/ Behaviour
1301 10-40%	dogs	Frightening situations (flashing light and noise)	none	NM	NM	NM	NM	Short of breath
1211 5% 10%	dogs	Exercising on treadmill	none	ND	1/6 at all Halon concentrations	NM	NM	Partially anesthetized. Could not continue running.
1301 10-80%	dogs and monkeys	2-3 mg/kg or 8-10 mg/kg	yes	yes at >10% Halon	yes cardiac arrest with 8-10 mg dose	NM	NM	dogs - epileptic monkeys - lethargic
1301	dogs	8-10 mg/kg	4/169	none	20%-8/13	NM	NM	NM

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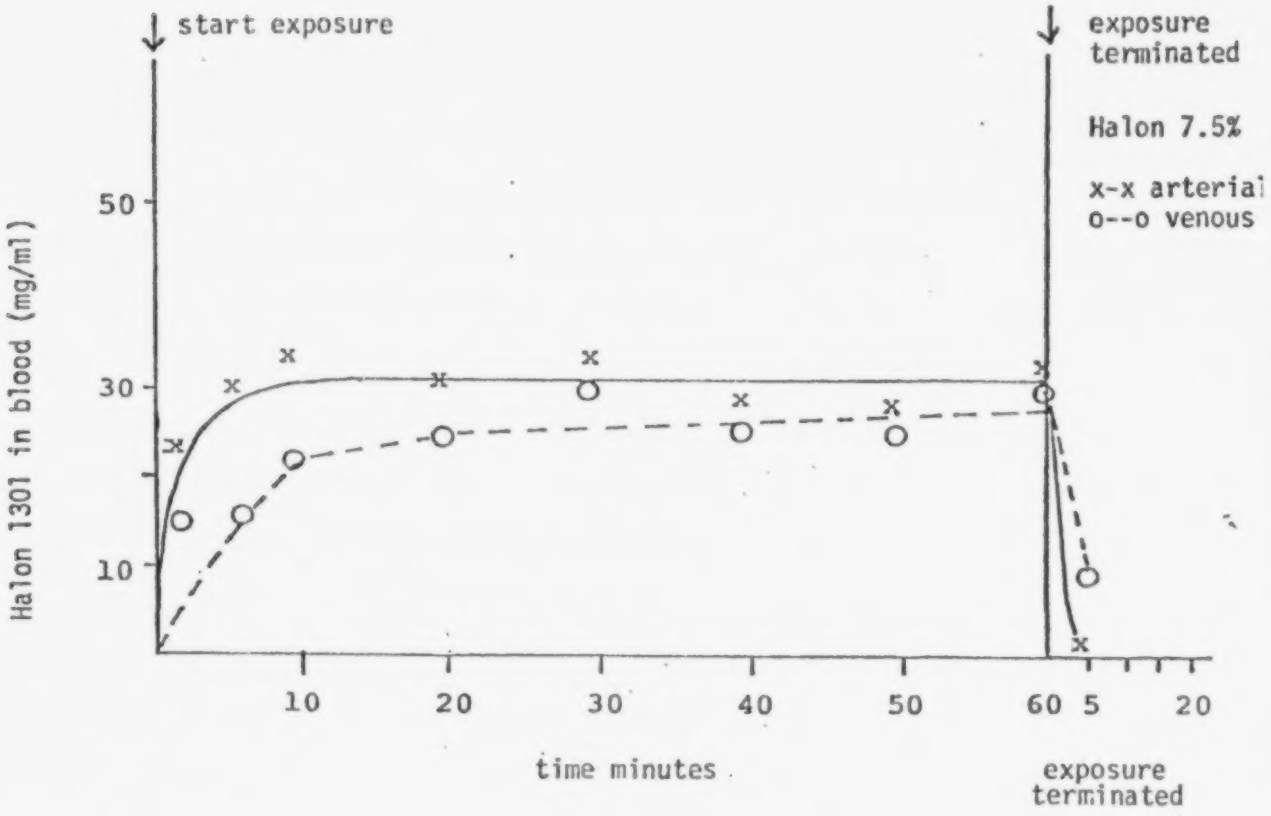
Fig. 1. Levels of Halon 1301 in blood of beagle dogs exposed to 1301 for 60 minutes



The principle route for clearance is presumed to be exhalation. One study of various tissues following Halon exposure has shown preferential uptake in adipose and brain tissue.

No detectable biochemical or enzymatic changes resulting from Halon 1301 exposure studies in animals have been reported to date indicating that this compound may not be metabolized [23, 28, 29].

A summary of experimental acute exposures of human volunteers to Halon 1301 is given in Table 7. These studies indicate that under non-stressful conditions, the cardiovascular effects of Halon 1301 are limited to increased pulse rate and decreased blood pressure. A single spontaneous cardiac arrhythmia was observed during a 5-minute exposure to 15% Halon 1301 [23]. However, CNS/behavioural effects were apparent in all studies. Thus, at concentrations up to 7% dizziness and lightheadedness were noted. These feelings increased as the concentration increased between 7 and 10% and response on a variety of performance tests decreased. Anesthesia became more prevalent above 10%.

Alveolar washout concentrations of Halon 1301 after 3 hours exposure of human subjects to 7% Halon 1301 showed the presence of the gas some 19 hours post-exposure indicating the presence of a slow washout compartment [30]. This study also presented data on the equilibrium concentration of Halon 1301 in venous blood, 125.4 mg/gm human. It should be stressed here that most human studies used small populations.

2. Chronic Exposures to Halon 1301

Results of some chronic exposure studies with animals are summarized in Table 8. Few recent data are available. It is apparent from these limited studies that chronic exposure to Halon 1301 is not expected to produce histological or biochemical effects.

No reports of chronic human experimental or occupational exposures to Halon 1301 have been found to date. This aspect apparently remains to be investigated.

3. Halon 1301 Contaminants

Early work on the toxicological aspects of Halon 1301 indicated the need for a very pure gas [23] for these studies. Thus, it was found that the LC_{50} [1] for Halon 1301 was much greater if the material was more than 99.9% pure. Current manufacturer's specifications are to this greater purity.

4. Thermal Degradation of Halon 1301

The products of pyrolysis for Halon 1301 are shown in Table 9 with their corresponding ALC, TLV and STEL values. Pyrolysis can occur at $>480^{o}C$ and the main products are hydrogen fluoride, hydrogen bromide and bromine. It should be noted that carbonyl halides have been detected at levels in excess of 1,955 ppm under certain test conditions. [31]. The final concentration of

[1] LC_{50} = lethal concentration required to kill 50% of the population.

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TABLE 7: A SUMMARY OF HUMAN EXPERIMENTAL ACUTE EXPOSURES TO HALON 1301

REFERENCE	NUMBER OF SUBJECTS	CONC. (%)	DURATION (MIN)	METHOD	RESULTS
Haskel Labs 1966 technical bulletin	3 multiple tests	1,3,5,7 10	3-3.5	Exposure booth	<7% no effects >7% behavioral change balance and reaction time change
Hine Labs 1969 technical bulletin	10	1-20	5	Face mask	10-15% Stage I Anesthetic 15-20% Stage II Anesthetic Pulse rate increased Blood pressure decreased *1 arrhythmia at 15%
Clark 1970	?	1-15	3	Face mask	Up to 9% dizziness and increase pulse rate; no ECG changes 10% dizzy within 1 mi T wave suppressio 12-15% severe dizziness panesthesis Recovery 1-5 min.

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TABLE 7: A SUMMARY OF HUMAN EXPERIMENTAL ACUTE EXPOSURES TO HALON 1301

REFERENCE	NUMBER OF SUBJECTS	CONC. (%)	DURATION (MIN)	METHOD	RESULTS
Call 1973 (18)	?	4, 7	3	Hypobaric exposure chamber 760, 632, 380 Torr	7% all pressures- dizziness No ECG changes 4 & 7% Rx time changes at all pressures.
Smith 1973 (Aero- space med.)	3	7	3	Airplane at 5000 ft (632 Torr) 18000 ft. (380 Torr) 20000 ft.	No behavioral changes No ECG changes
Stewart 1978 (unpub.)	?	1-7.1	30	?	No ECG changes light headedness Decrease on balance and menta performance tests
Harrison 1982	6	7	3hrs	Controlled environment chamber	Preliminary repor no change in ECG, blood pressure or biochem. para- meters; light headedness and changes in per- formance tests apparent.

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TABLE 8: SUMMARY OF STUDIES ON THE TOXICOLOGICAL EFFECT OF CHRONIC EXPOSURE TO HALON 1301

REFERENCE	TEST ANIMAL	HALON 1301 CONC. (%)	EXPOSURE DURATION	RESULTS
Comstock 1957	rat	2.3	6hr/day 5 day/wk	- no clinical toxicity - no autopsy charges except lung congestion
Paulet 1962	rat	50.0	2 hr/day 15 days	- no histological change observed
Griffin	rat	5.0	23 hr/day 30 days	- no effect on serum electrolytes or heometolytic parameter - no autopsy or histological change - no accumulation of 130 in blood once steady state reached

pyrolysis products depends on the method [27, 32], temperature of pyrolysis [23, 25] and Halon concentration.

Test animal exposures to the pyrolysis products of seven Halons including 1301 have provided some basic information as to their toxicity (Table 10) [21]. Although Halon 1301 decomposition products are the least toxic they are nevertheless eminently more toxic than the pure substance. The causative agent for the lethal effects of exposure to the decomposition products of Halon 1301 is believed to be hydrogen fluoride because of the similarity in ALC values and delayed onset of the effects that is, pulmonary oedema and hemorrhage common to overexposure to hydrogen fluoride.

Sublethal effects of exposure to decomposition products of Halon 1301 consist primarily of irritation of the mucosal membranes. This irritative ability provides good warning for the presence of these compounds albeit with a large individual variability in sensitivity.

No human exposure studies to pyrolysis products of Halon 1301 have been reported to date.

The presumed absence of live flame during QNFT tests with Halon 1301 somewhat precludes the occurrence of extensive degradation of this gas. Nevertheless, the presence of hot surfaces in the test area may lead to the production of significant amounts of hydrogen fluoride and other decomposition products.

5. Route(s) of Absorption

From the many studies conducted to date with Halon 1301, it is apparent that the most important route of absorption for this gas is inhalation. This substance exists as a gas at room

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TABLE 9: HALON 1301 DECOMPOSITION PRODUCTS

COMPOUND	ALC (15 min.) ppm vol/air	TLV (ppm)	STEL (ppm)
HYDROGEN FLUORIDE HF	2,500	3.0	6.0
HYDROGEN BROMIDE HBr	4,750	3.0	---
BROMINE Br_2	550	0.1	0.3
CARBONYL FLUORIDE COF_2	1,500	2.0	5.0
CARBONYL BROMIDE COB_2	100-150*	0.1*	0.4*

*Value for phosgene, $COCl_2$

TABLE 10: APPROXIMATE LETHAL CONCENTRATIONS (ALC) FOR 15 MINUTES EXPOSURE TO THE PYROLYZED VAPOURS OF VARIOUS HALON FIRE EXTINGUISHING AGENTS

AGENT	FORMULA	HALON	ALC (ppm)
CARBON TETRACHLORIDE	CCl_4	104	300
DIBROMOTETRAFLUOROMETHANE	BrF_2CCBrF_2	2402	1600
DIBROMODIFLUOROMETHANE	CBR_2F_2	1202	1850
BROMOCHLOROMETHANE	CH_2BrCl	1011	4000
BROMOCHLORODIFLUOROMETHANE	CBr_2ClF_2	1211	7650
METHYL BROMIDE	CH_3Br	1001	9600
BROMOTRIFLUOROMETHANE	$CBrF_3$	1301	14000

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temperature and although one cannot eliminate the possibility of skin absorption for this halocarbon, it is highly probable that this route of absorption plays a minor role.

Sulphur Hexafluoride (SF_6)

SF_6 was discovered by Moissan and Lebeau in 1900 [33]. Its physical and chemical properties are outlined in Table 11. Essentially, it is an heavier than air gas whose chemical inertness and physiological passivity rival that of nitrogen and helium. This inherent inertness is probably due to the molecule's high symmetry and its small, strongly bonded fluorine atoms. Atmospheric concentrations of this gas are less than 2 ppt by volume.

Its properties make it a perfect gas for electrical insulation and this is its main commercial use today. It has been used extensively as a tracer gas to determine pollution transport, building ventilation, laboratory hood performance, local exhaust system performance, mine ventilation and rock porosity and permeability studies [34-37]. In all these studies, involving ambient concentrations of 10 ppm SF_6 or less, the test was conducted in occupied workplaces.

SULFUR HEXAFLUORIDE

Physical Properties

Molecular Weight	146
Vapour Pressure	22.77 atm
Absolute Density, Gas at 101.325 kPa	6.162 kg/m^3
Relative Density, Gas at 101.325 kPa	5.114
Solubility in Water	5.4 cm^3/kg water

TABLE 11: PHYSICO-CHEMICAL PROPERTIES OF SULFUR HEXAFLUORIDE(SF_6)

1. Acute Exposure

Pure SF_6 is non-toxic and classified as a simple asphyxiant like nitrogen gas. Human volunteers have been exposed to an atmosphere of 79% SF_6 and 21% O_2 with no detectable deterioration of health [38]. In fact, the gas was used to perform pulmonary function tests where patients had their lungs filled with 80% SF_6 and 20% O_2 with no side effects observed [39]. Similar experiments have been conducted with rats.

2. Chronic Exposure

No chronic exposure studies with SF_6 were found in the literature. However, twenty years experience in handling devices

filled with SF_6 as insulating gas in the electrical industry apparently attests to its lack of chronic toxicity.

3. Route(s) of Absorption

The main route of absorption is via inhalation. Although skin absorption cannot be eliminated, this route is highly unlikely for this gas.

4. Toxic Contaminant [39]

Highly toxic impurities in SF_6 can arise in very small concentrations from the manufacturing processes. These include hydrogen fluoride, S_2F_{10} and SF_4. A biological test has been proposed for all toxic impurities including subanalytical concentrations. This involves the exposure of five female Albino mice to an atmosphere of 79% SF_6 and 21% O_2 for 24 hours [40]. All SF_6 supplied for electrical installation are, reportedly at least, tested in this manner.

5. Thermal Decomposition

The Atomic, Molecular and High Voltage Physics Group at Oak Ridge National Laboratory has been analysing the chemical nature of spark decomposition products of SF_6 for some years [41]. Figure 2 shows some of the major decomposition products identified [42, 43]. Other potential by-products of lower abundance include SOF_4 and S_2F_{10}. An investigation of the biological activity of these by-products has also been conducted using 'in vitro' cell culture techniques in a rapid assay for cytotoxic effects. They have found

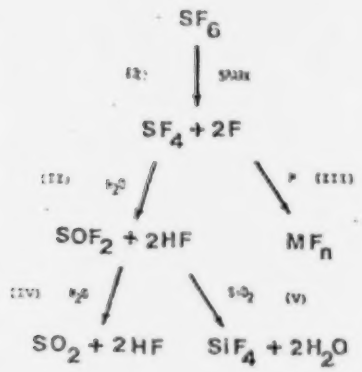

FIGURE 2: DECOMPOSITION PRODUCTS FROM SPARKED SF_6 [43]

that commercial grade SF_6 does not have a cytotoxic effect even when cells are exposed for 48 hours to a 95% SF_6-5% air mixture. Conversely, sparked SF_6 exhibited a strong cytotoxic effect. This toxicity was found to increase with time and exposure. Preliminary results have not yet identified with certainty the main causative agents amongst all the decomposition products. However, the studies did demonstrate the toxicity of sparked SF_6 gas.

It has also been demonstrated that SF_6 gas exposed to surfaces or temperatures in excess of 550°C will decompose to produce the highly toxic sulphur tetrafluoride (SF_4) whose short-term exposure limit according to the American Conference of Gouvernmental Industrial Hygienists is 0.4 mg/m^3.

Freon 12 (dichlorodifluoromethane)

Commonly used as a refrigerant, propellant and foam blowing agent. Its chemical and physical properties are listed in Table 12.

1. Acute Exposure

Essentially, inhaled Freon 12 has very low acute toxicity and acts like a weak narcotic. Sayers et al. [44] exposed dogs, monkeys and guinea pigs to 20% vol/vol Freon 12 for seven hours daily for 12 weeks and reported some distinct symptoms but no signs of severe poisoning. Additional supportive information was provided by Lester and Greenberg [45] who noted muscular twitching in rats exposed for two hours to 20-40% vol/vol Freon 12. They further reported deep anesthesia but no mortality in rats exposed to 80% Freon 12 and 20% oxygen. Neither permanent effects nor pathological changes were noted in their studies.

Kehoe [46] exposed two human subjects to concentrations of Freon 12 ranging from 4 to 11 vol/vol% for up to 80 minutes. The subjects reported such symptoms as generalized tingling sensation, humming in the ears, apprehension, changes in the electroencephalogram, decreased psychological test scores, slurred speech at the 4% level. The intensity of the cortical depression increased concomitantly with Freon 12 concentrations with amnesia occurring in 10 minutes at the 11% level accompanied by a significant degree of cardiac arrhythmias. Agar et al. [47] using two human volunteers found no adverse effect resulting from exposure to 1000 ppm for 2.5 hours and only a 7% reduction of the standardized psychrometer test after exposure to 10,000 ppm of this

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TABLE 12: PHYSICAL AND CHEMICAL PROPERTIES OF FREON 12 (DICHLORODIFLUOROMETHANE)

Physical Data

Odorless

Molecular Weight	120.9
Boiling Point	-29.8 °C (760 mm Hg)
Vapour Density (air = 1)	4.2
Vapour Pressure (20 °C)	5.7 atmospheres
Solubility in water	0.008 g/100 g water at 20 °C
Evaporation Rate (butyl acetate = 1)	380

Reactivity

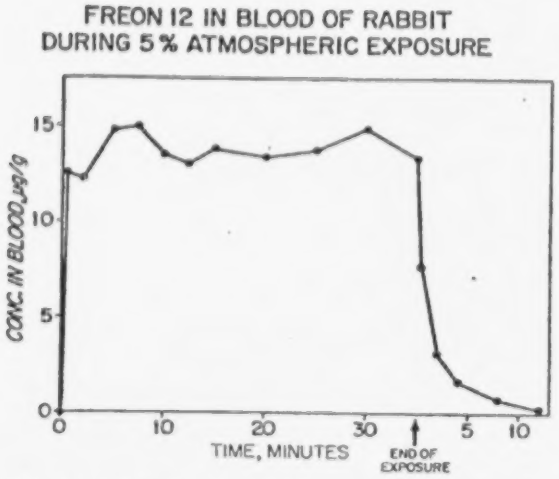
Decomposed by heat

Reacts with powdered aluminium, zinc and magnesium

Non-flammable

agent for a similar period. Measurement of the subjects end-tidal air immediately post-exposure demonstrated that the compound is rapidly eliminated from the lungs.

Cardiac sensitization potential for Freon 12 is considered moderate. Reinhardt et al. [48] have demonstrated the sensitizing of the dog's heart after exposure of the dogs to 50,000 ppm of the gas and intravenous epinephrine. This sensitization of the heart can be induced at 100,000-800,000 ppm without endogenous epinephrine. It should be noted that compounds containing chlorine, such as Freon 12, are potent cardiac sensitizers. The rapid equilibration and short half-life of Freon 12 in rabbit blood in shown in Figure 3 [49].



Freon 12 in blood of rabbit during 5% atmospheric exposure. Blood samples were withdrawn from the animals before, during and after exposure to Freon 12 and the halocarbon concentrations determined by gas-liquid chromatography.

FIGURE 3

2. Chronic Exposure

Chronic studies with Freon 12 reveal few biologic effects. Thus, rats administered up to 379 mg/Kg, five days/week for 18 weeks [50], showed no clinical, nutritional, histologic or enzyme changes except for a slight elevation of plasma alkaline phosphatase. Dogs administered 3000 ppm for two years showed no evidence of toxicity [51]. Carcinogenic, mutagenic and three-generation reproductive studies in rats given 3000 ppm for two years showed no adverse effects. An Ames bacterial mutagen test was negative [52]. One of the more notable studies has been a 90-day continuous exposure of multiple species to 810 ppm of Freon 12 with the only adverse effect being mild liver damage in guinea pigs only [53].

3. Route(s) of Absorption

The principal route of absorption for this gaseous substance is inhalation. Skin and eye absorption can take place. However, it is likely to have less importance than absorption via inhalation.

4. Toxic Contaminants

Very high purity Freon 12 is commercially available: food-grade, manufactured by E. I. duPont de Nemours (99.8 + % Freon 12, 0.009% Freon 22, 0.003% Freon 21).

5. Thermal Decomposition

Toxic gases and vapours including hydrogen chloride, hydrogen fluoride, phosgene are released when Freon 12 is decomposed thermally.

Freon 116 (hexafluoroethane)

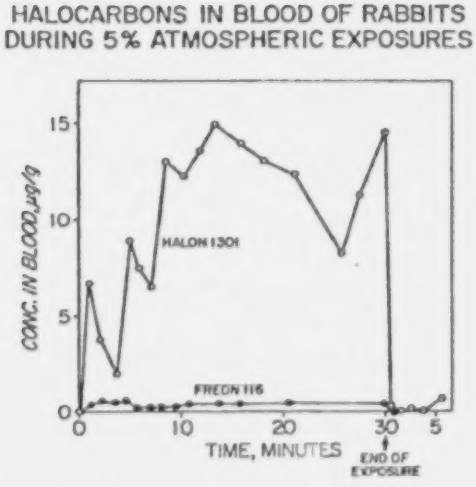
This agent has been proposed as a fire suppressant in space crafts where it would deliberately be admixed with the spacecraft's atmosphere resulting in continuous exposure of its occupants. Its physical and chemical properties are shown in Table 13.

Acute Exposure

Griffin et al. [49] conducted similar tests with Freon 116 as with Freon C-318 with similar results - little or no toxic effects from single or multiple exposures of rats and guinea pigs to 20% atmospheres of the gas. They found that Freon 116 was among the least active cardiac sensitizers. They also determined the uptake and clearance of Freon 116 from the blood of rabbits exposed to 5% vol/vol of this gas. The results shown in Figure 4 compare parameters for Freon 116 with those obtained for Halon 1301. The highest level of the halocarbon (Freon 116) attained in the animal's blood was less than one µg/gm and much less than the level reached by Halon 1301. The levels of both fluorocarbons returned to unmeasureable levels within one or two minutes after cessation of exposure.

TABLE 13: PHYSICAL AND CHEMICAL PROPERTIES OF FREON 116
(hexafluoroethane)

Physical Data	
Boiling Point	-78.2oC
Melting Point	-100.6oC
Sp. Gr.	- 1.59
Molecular Weight	138.02



Halocarbons in blood of rabbits during 5% atmospheric exposures. Blood samples were withdrawn from the animals before, during and after exposures to either Halon 1301 (open circles) or Freon 116 (solid circles). Concentrations of the halocarbons in blood were determined by gas-liquid chromatography.

FIGURE 4: HALOCARBONS IN BLOOD OF RABBITS
DURING 5% ATMOSPHERIC EXPOSURES

Freon C-318 (Octafluorocyclobutane)

A low pressure propellant used for foodstuff and as a dielectric gas. Its chemical and physical properties are listed in Table 14.

TABLE 14: PHYSICAL AND CHEMICAL PROPERTIES OF FREON C-318 (Octafluorocyclobutane)

Physical Data	
Molecular Weight	200
Boiling Point	-5.8°C (at 760 mm Hg)
Vapour Pressure (20°C)	25.4 psig

1. Acute Exposure

Animal experiments conducted by Griffin et al. [49] have shown that test animals (rats and guinea pigs) tolerated atmospheres containing 20% of this gas with no difficulty. In acute inhalation experiments, rats survived a mixture of 80% in oxygen for four hours [54]. However, physiological measurements indicate that inhalation of 10% Freon C-318 can cause the following: bronchoconstriction and reduced compliance in dogs [55] and rats [56]; myocardial depression in the monkey [57] and sensitization to epinephrine-induced arrhythmias in the dog and mouse [58]. The exposures were either single or multiple. Studies conducted by Aviado et al. [59] on the effects of aerosol propellants on the respiratory and circulatory systems in primates have shown that Freon C-318 causes an increase in pulmonary resistance but has no effect on minute volumes, heart rate or basal pressure.

2. Chronic Exposure

The chronic effects in aminals of Freon C-318 has been investigated by Bashkov [60] and Paulet et al. [61]. In none of this work were histological signs of toxicity to the lungs noted.

Halothane (trifluorochlorobromoethane)

Halothane has been in use in most hospitals since 1956 as an inhalation anesthetic. Like all other modern day anesthetics, it was formulated to fulfill the twin objectives sought in these

compounds that is, decreased volatility with increased metabolic stability and effectiveness. These goals were achieved by introducing halogen, mainly fluorine, into the molecule. In fact, its metabolic stability does increase in direct proportion to its fluorine content. Its anesthetic potency also depends on its solubility in fatty tissue. Halothane was considered one of the best of the fluorinated agents because of its volatility, non-explosiveness when mixed with oxygen and its apparent lack of any serious physiologic side effects.

At the outset, compounds like halothane were thought to be "inert" and metabolically unreactive as a result of extensive testing with various animal species. However, over 50% of the toxic effects elicited in humans by these compounds had been missed in animals whereas 20% of the toxic effects predicted by these studies never occurred. Hence, reliance in what follows will be placed on toxic effects found in human subjects through use of halothane as an anesthetic.

1. Acute Exposure

Anesthesia in human patients is generally incuded with a mixture of an anesthetic such as halothane, an anesthetic gas, nitrous oxide, and oxygen. The amount of halothane used to induce anesthesia ranges from 0.25 - 1.5% vol/vol. Hence, this could be likened to an acute exposure and the toxic effects observed in patients post-anesthesia will be reviewed.

As shown in Table 15 [62], halothane concentration in tissue increases concomitantly with duration of anesthesia, the fatty tissue showing the greater increase. Figure 5 illustrates the

TABLE 15

RETENTION OF HALOTHANE (mg/100 g) IN BLOOD AND SEVERAL SOFT TISSUES AFTER DIFFERENT LENGTHS OF TIME OF ANESTHESIA

	Duration of anesthesia (Hr)							
Tissue	0.5	1.0	1.5	2.0	2.5	3.0	4.5	6.0
Blood	15.1	16.9	18.0	16.8	21.0	22.0	18.5	21.5
Fat	55	100	130	250	300	450	650	950
Brain	20	25	20	31	31	33	38	45
Liver	17	22	18	23	26	35	43	48

Source. Adapted from Duncan and Raventos (1959) [62]

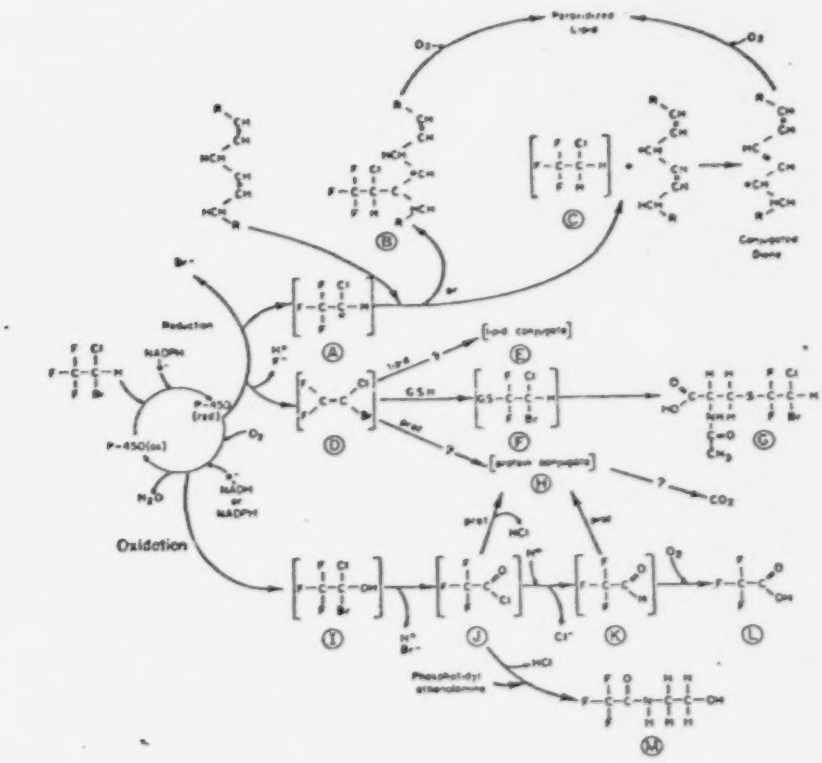


FIGURE 5: Halothane metabolism by reductive or oxidative pathways, showing the various intermediated that may be formed [63].

metabolic breakdown of halothane and the conjugations which occur. Most of this biotransformation occurs in the liver [63].

One of the main clinical anesthesia syndromes observed post anesthesia has been "halothane hepatitis" and the latter has been the subject of a "National Halothane Study" in the United States [64]. The incidence of this disease and clinical symptomology are shown in Tables 16 and 17 respectively. Post operative fever is common with jaundice and hepatitis appearing 3 to 21 days post exposure. Multiple exposures to this agent increase the likelihood of adverse physiologic responses. Obesity has also been cited as an important factor in the potentiation of adverse effects because of the ability for obese persons to retain more halothane. There is, to date, no simple explanation for anesthetic-associated hepatotoxicity. A general viewpoint is that none of the known metabolites is responsible for this effect. It has also been suggested that susceptible persons such as individuals with autoimmune disease are paticularly at risk [69].

2. Chronic Exposure

Epidemiological studies have indicated that low-dose long-term occupational exposures to anesthetic environments may lead to serious physiologic effects (Table 18). Metabolic aberrations are a direct function of the intensity of exposure. The "carrier" effect, i.e., wives of exposed dentists having 78% higher than normal rate of spontaneous abortion, should be noted. Hepatotoxicity is also a possibility following chronic exposure to halothane.

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TABLE 16

INCIDENCE OF HALOTHANE-ASSOCIATED HEPATOTOXICITY

Type of toxic impact	Incidence (and circumstances)	Reference
Fatal massive hepatic necrosis	1/35,000 (halothane vs total anesthesias) 1/10,000 (halothane and other anesthetics)	Simpson *et al.*, 1972
Fatal hepatic necrosis and jaundice	1/30,000 (halothane vs total anesthesias)	Holaday and Fiserova-B., 197
Death from massive hepatic necrosis	1/10,000 (halothane associated)	Rosenberg, 1972
Deaths from liver necrosis Hepatitis (following halothane use)	1.25/10,000 (halothane associated) 18% of 400 cases (1958–1968)	Gottlieb and Trey, 1974
Massive hepatic necrosis	7.1/10,000 (multiple exposure to halothane) 2.1/10,000 (exposed to other anesthetics)	Davis, 1972
Massive hepatic necrosis	7.1/10,000 (multiple halothane) 3.0/10,000 (halothane and other anesthetics) 2.4/10,000 (multiple nonhalothane anesthetics) 0.7/10,000 (single anesthesia)	Dykes *et al.*, 1972
Hepatic necrosis Death among hepatic necrosis patients	7/10,000 (multiple exposure to halothane) 46% (139 of 300 cases during 1963–1976)	Sherlock, 1978
Jaundice	11/10,000 (during 1953–1956) 42/10,000 (during 1960–1963) 41/10,000 (halothane-associated, 1960–1963)	Simpson *et al.*, 1972

TABLE 17

CLINICAL SYNDROME OF HALOTHANE-ASSOCIATED HEPATITIS

AGE	Any age, but predominantly over 40 years.
SEX	Both sexes, females predominate.
INCIDENCE	Not established. Presumed mortality 1:10,000 halothane anesthesias or 1:1000 multiple exposures to halothane.
CLINICAL FEATURES	1. Multiple exposures, usually within 60 days. 2. Not dose related. 3. Usually reported in patients without prior history of liver disease. 4. Course varies from anioteric hepatitis to massive hepatic necrosis. Can have cholestatic phase. 5. Unexplained postoperative fever is common. 6. Eosinophilia reported. 7. Jaundice and hepatitis--usually 3 to 21 days postexposure. 8. Cross-reactivity with methoxyflurane.
PATHOLOGY	Similar to viral or hepatotoxic hepatitis.
MODE OF ACTION	halothane undergoes biotransformation. No animal model has reproduced complete syndrome. Hepatitis presumed by sensitization.

Source. Adapted from Gottlieb and Trey (1974) [68].

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TABLE 18 [65]
METABOLIC EFFECTS OF LOW-DOSE LONG-TERM OCCUPATIONAL EXPOSURES TO ANESTHETIC ENVIRONMENTS

Types of subjects compared	Metabolic aberration	Increased incidence (n-fold)
Exposed dentists vs. controls	Liver disease	2.56
Exposed females vs. nonexposed females	Hepatic disease (excluding serum hepatitis)	1.3-2.20
Female physician anesthetists vs. controls	Spontaneous abortion	3.8
Operating room nurses vs. controls		3.0
Active female anesthetists vs. same group, preemployment.	Spontaneous abortion	2.0
Active female anesthetists vs. retired female anesthetists		1.33
Wives of exposed dentists vs. controls	Spontaneous abortion	1.78
Female physician anesthetists vs. unexposed female physicians	Fetal congenital abnormalities	2.0
Exposed nurse anesthetists vs. unexposed nurses	Fetal abnormalities	1.6
Unexposed wives of male anesthetists vs. controls	Fetal congenital malformations	1.25
Nurse anesthetists vs. controls	Malignancy*(reticulo-endothelial and lymphoid)	3.0
Female physician anesthetists vs. unexposed female pediatricians	Malignancy*(reticulo-endothelial and lymphoid)	2.0

Source. Tabulated from Vaughn et al. (1978) [66]; also Cohen and VanDyke (1977) [67].
* Does not apply to exposed males.

As early as 1967, Vaisman [70] reported an increased incidence of reproductive failure in women working in operating rooms and this has sparked an interest in the potential consequences of occupational exposure to anesthetic gases to this day. It is noteworthy that halothane has been detected in the expired air of anesthesiologists for 7-64 hours after exposure to 1-10 ppm for 20-390 minutes [71]. A retrospective study of mortality amongst anesthesiologists over a 20-year period has found significantly higher death rates from malignancies of lymphoid-reticuloendothelial origin. A higher than expected incidence of malignancies amongst Michigan nurse-anesthetists, during 1971 has also been reported [72]. Reproductive histories of operating room personnel have been surveyed and the results of two such surveys are shown in Table 19 [73] revealed high incidences of spontaneous miscarriages. it should also be mentioned that there is concern for both the potential teratogenic [74] and carcinogenic [73] effects of exposure to anesthetics such as halothane. Studies have identified a higher than normal incidence of congenital abnormalities among the children of personnel exposed to anesthetic gases (Table 20) [73].

3. Route(s) of Absorption

Although inhalation is a primary route of absorption, skin absorption is a distinct possibility especially if there is contact between the intact skin and the liquid anesthetic.

TABLE 19 [73]

SUMMARY OF SPONTANEOUS ABORTION RATES
FROM EPIDEMIOLOGIC STUDIES* IN PERSONNEL
EXPOSED TO ANESTHETIC GASES

Exposed Group (E)	Spontaneous Abortion Rate, % E	C	Control Group (C)
Operating room nurses	29.7	8.8	General duty nurses
Female anesthetists	37.8	10.3	Female physicians
Female anesthetists	18.2	14.7	Female physicians
Female anesthetists	17.1	8.9	Female physicians
Nurse-anesthetists	17.0	15.1	General duty nurses
Operating room nurses	19.5	15.1	General duty nurses
Wives of exposed dentists	16.0	9.0	Wives of unexposed dentists
Female anesthetists	17.9	10.6	Before exposure
Maternal exposure	15.5	10.9	Neither parent exposed

*Studies listed are limited to those utilizing a control group.

TABLE 20 [73]

SUMMARY OF CONGENITAL ABNORMALITY RATES
FROM EPIDEMIOLOGIC STUDIES* IN PERSONNEL
EXPOSED TO ANESTHETIC GASES

Exposed Group (E)	Congenital Abnormality Rate, % E	C	Control Group (C)
Female anesthesiologists	5.9	3.0	Female pediatricians
Nurse-anesthetists	9.6	7.6	General duty nurses
Nurse-anesthetists	9.6	5.9	Unexposed nurse-anesthetists
Wives of exposed dentists	4.7	4.1	Wives of unexposed dentists
Maternal exposure	5.5	3.6	Neither parent exposed
Paternal exposure	4.5	3.6	Neither parent exposed.

*Studies listed are limited to those utilizing a control group.

4. Toxic Contaminants

Halothane is available at a high level of purity (99.9+%) because of its use as an anesthetic.

5. Thermal Decomposition

No information was found in the literature concerning the thermal decomposition of halothane. However, like other halocarbons, it is expected that it would decompose into hydrogen bromide, hydrogen chloride, bromine and possibly chlorine on thermal decomposition (see Halon 1301). Phosgene is also a distinct possibility.

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ADSORPTION ON CHARCOAL

An accurate evaluation of environmental conditions as well as work functions is essential if an organic vapour/gas air purifying device is to be properly chosen. Removal of the contaminant on inhalation by interaction of the molecules with granular porous material-sorbent is one of the basic properties which every air purifying vapour/gas device must possess. Different types of forces can be involved and sorption is usually classified according to these types of interaction [75]. If only physical forces are involved, the process is called adsorption (activated carbon black, charcoal). Should the interaction be stronger (electron transfer mechanism), the phenomenon is termed chemi-sorption (soda-lime, cupramite, acid-impregnated solid adsorbents, acidic alumina, amine impreganted activated carbon and metal oxides). However, if the sorbate does not remain on the surface, but enters into the solid or its impregnant and reacts chemically with it, and thus changes the chemical nature of each, the process is called absorption. In addition, the sorbent could act solely as a catalyst (hopcalite) which decomposes and thus detoxifies the contaminant by formation of relatively innocuous substances which can be adsorbed, chemisorbed, or absorbed [75].

Depending on the properties of both the sorbent and sorbate the amount of gas/vapour sorbed may be small or large. Also, these sorbents must function well under varying conditions of temperature, humidity, flow rate, concentration of contaminants, etc. The flow rate is probably the factor displaying the greatest variance and peak flows may vary between 15 lpm up to 100 lpm [75].

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Ideally the sorbent should:

a) have a high capacity;

b) adsorb at high rates;

c) be able to retain its shape (not crumble);

d) display high retention.

In addition, the sorbent should be able to maintain all of these properties under normal storage and use conditions. The sorbing capability and capacity of a material may be influenced by many factors. To date, no single physical characteristic of the contaminant or sorbent has been identified that consistently correlates with adsorption capacity and service life. There are, however, some factors known to play a major role in the determination of particular sorbent needs [75]:

a) type and rate of flow;

b) humidity (relative and absolute);

c) concentration of contaminant;

d) temperature;

e) physical-chemical properties of sorbent (surface area, porosity, surface characteristics);

f) size of granules and relationship to surface area;

g) activity of sorbent;

h) capacity of sorbent;

i) physical and chemical properties of the gases and vapours (polarizability, dipole moment, quadrupole moment, etc.);

j) desorption characteristics;

k) void fraction.

Extensive work on the performance of air purifying cartridges has been done by Nelson et al. [76-82].

Type and Rate of Air Flow

Nelson and Harder showed that the cartridge (charcoal) service life (breakthrough) is inversely proportional to flow rate for acetone and benzene [81]. The effect of flow rate varies with the sorbent. In some cases once the optimum flow rate is reached no increase in breakthrough volume is observed with reduction of the flow rate [83]. The work of Saalwaechter et al. [83], indicates that with a steady flow of most organic vapours into the sorbent bed the charcoal will normally collect one hundred per-cent (100%) of the vapour for a time. Eventually, a small amount of the contaminant will begin to pass through the bed (breakthrough point). After this point, although the bed still adsorbs some contaminant, the amount breaking through increases until the exit concentration equals the inlet concentration. The authors further concluded, that the lower flow rates may have the added advantage of increasing the breakthrough volume since the vapours will have a longer time to equilibrate over the whole surface of the charcoal [83]. Nelson et al. investigated the influence of pulsating flow or charcoal adsorption in comparison with steady-state flow [80] and concluded that no significant difference exists between the two modes, which conforms to basic adsorption theory, whereby the equilibrium between the vapour and the absorbent should be practically instantaneous [84]. Nelson and Harder further concluded that the amount of solvent adsorbed at a given temperature, humidity and concentration is essentially constant (see Fig. 6) and is independent of the flow rate in the range normally associated with human breathing [80].

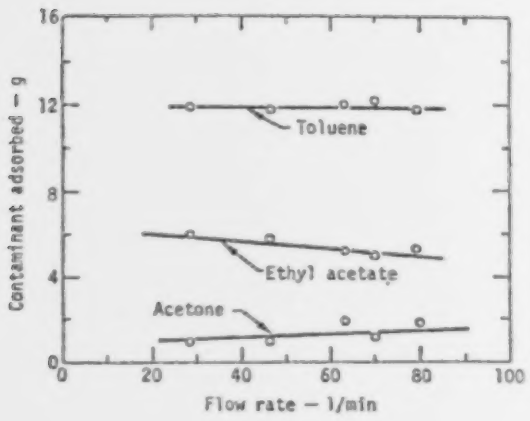

FIGURE 6: Contaminant adsorption is essentially constant under given conditions and independent of the flow rate [80].

Humidity

The influence of humidity on charcoal's ability to absorb gases and/or vapours has been studied by Maggs and Smith [85], Nelson et al. [82] and Balieu [86]. Balieu has shown that the penetration (of contaminant) depends on the humidity of the air and that penetration increases with the increase of humidity; this translates into a decrease in service time (reduced sorption) with increased humidity [86]. The phenomenon is shown in Fig. 7.

Nelson and Harder studied the effects of relative humidity on charcoal's retention and have shown the log of the 10°C breakthrough time as a function of the log of the benzene concentration for three flow rates (Fig. 8) and pointed out that three aspects of the figure should be noted.

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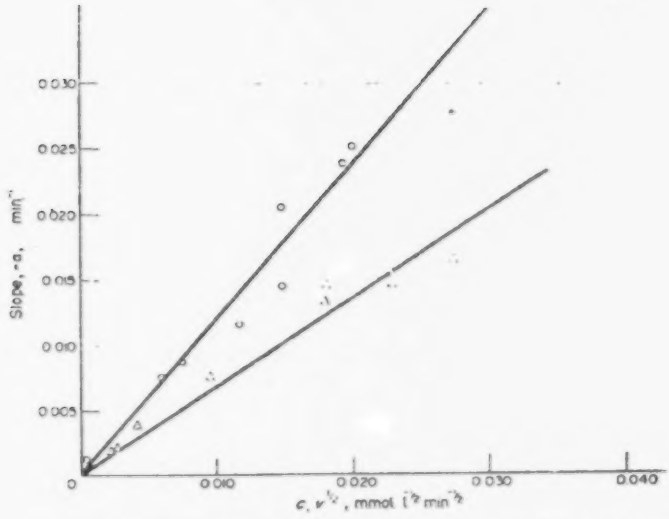

. Plot of $-a$ vs $c_i v^{1/2}$ for the tests under dry (△) and humid (○) conditions.

FIGURE 7: Plot of slope vs. $C_i v^{1/2}$ for the tests under dry (Δ) and humid (o) conditions [86].

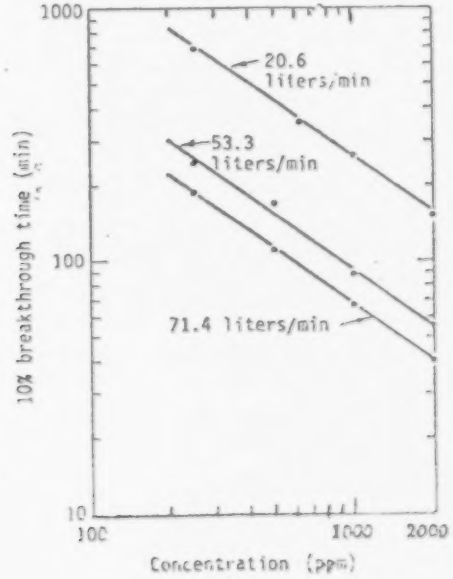

FIGURE 8 [82]

The effect of concentration on the 10% breakthrough time of benzene at various flow rates.

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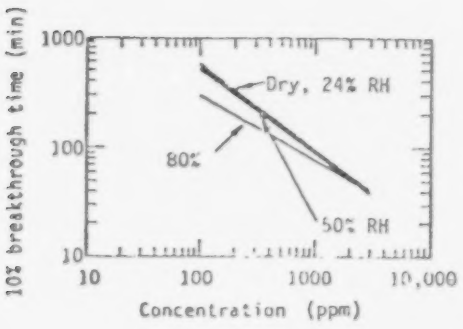
a) the relationship is linear;

b) the parallelism of the three flow rates indicates approximately constant slopes;

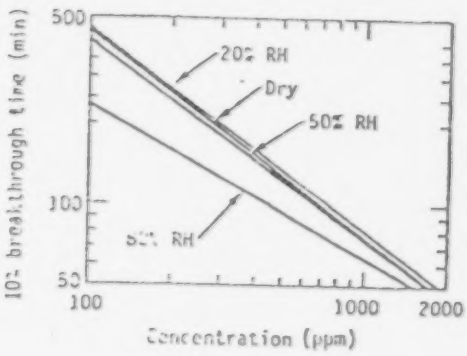
c) the ratios of the breakthrough times at a given concentration are inversely proportional to flow rate over the concentration range of 100 to 2000 ppm.

The authors further pointed out that as the concentration decreases, the breakthrough-concentration lines begin to spread indicating that at lower concentrations the breakthrough times are more seriously decreased by the higher humidities, as shown in Figures 9 and 10.



The effect of concentration on the 10% breakthrough time of benzene at various humidities.

FIGURE 9



The effect of concentration on the 10% breakthrough time of methylchloroform at various humidities.

FIGURE 10

This can be explained, in part, by the competition of the solvent and water vapour for an available adsorption site on the activated carbon. Saalwaechter et al [83] concluded in their study as well that "wet" samples gave very erratic and generally low results and that humidity as high as 94% does affect the "breakthrough volume" of toluene.

Temperature

Melcher et al. [87] stated that an increase in temperature will result in an increase in breakthrough. Unfortunately, there is little specific information available for various solvents. For charcoal a general guideline has been suggested [82] that for every 10°C rise in the temperature the breakthrough time will be reduced by 1-10%. After carrying out a series of experiments (see Table 21), Saalwaechter et al [83] concluded that heat cycles do not affect the amount of contaminant which can be removed from charcoal.

Exposure to Heat Cycles
Toluene and Styrene

Storage Conditions	Amount Found on Tube (mg)* Toluene	Styrene
Control - 25°C	6.82	7.56
8 hr @ 48°C and then storage @ 25°C	6.87	7.15
Three 8 hr periods @ 48°C alternated with 16-hr periods @ 25°C	6.89	7.60
Seven 8 hr periods @ 48°C alternated with 16 hr periods @ 25°C	6 88	7.46
Three 8 hr periods @ 48°C alternated with 16 hr periods @ -13°C	6.94	—
Two 8 hr periods @ -13°C alternated with 16 hr periods @ 25°C	—	7 50

TABLE 21: EXPOSURE TO HEAT CYCLES - TOLUENE AND STYRENE [83]

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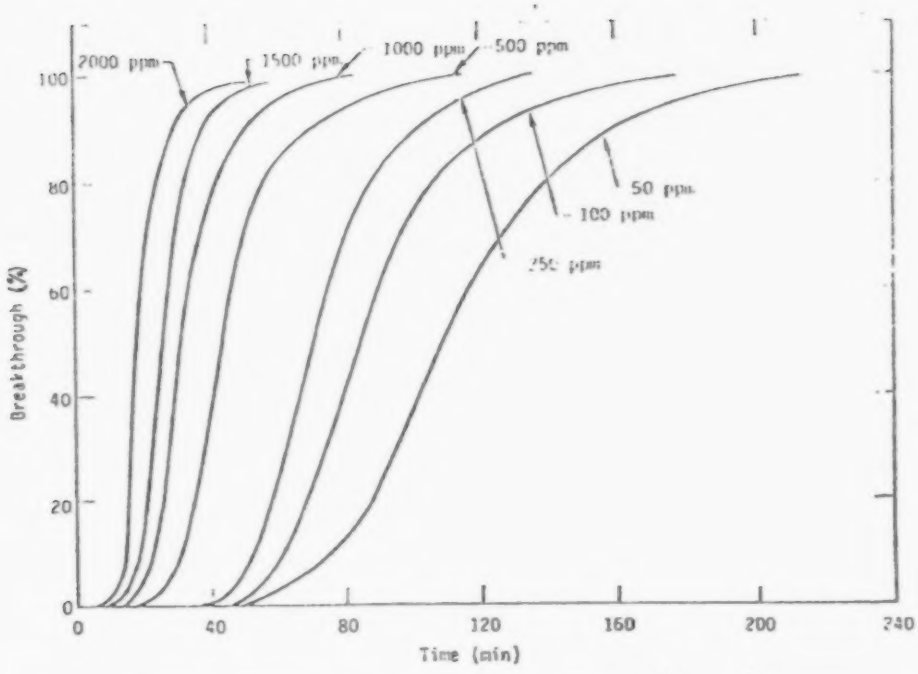
This is an important characteristic for charcoal canisters used repeatedly but not continuously and stored between the applications.

Coadsorption

The effect of coadsorption on breakthrough on one compound was investigated by Melcher et al. [87]. Results are shown in Figure 11 when two or more compounds are collected. Thus, the compound most strongly held will displace the other compounds, in order, down the length of the sorbent bed (Fig. 11). For a polar sorbent, compounds with large dielectric constant and dipole moment are most strongly held. For non-polar compounds, preferences are usually for the compounds of a higher boiling point or a larger molecular volume [88].

Contaminant Concentration

Nelson and Harder [81] studied the effect of contaminant concentration or breakthrough time on vinyl chloride using concentrations from 50 ppm to 2000 ppm. The results of their study are shown in Figure 11 and Table 22, where the 10% breakthrough time is shown as a function of concentration for three types of cartridges.



Breakthrough curves for Type 2 cartridges at various concentrations of vinyl chloride.

FIGURE 11

The 10% Breakthrough Times as a Function of Vinyl Chloride Concentration for Three Types of Cartridges[a]

CONCENTRATION (PPM)	10% BREAKTHROUGH TIME (MIN)		
	TYPE 1	TYPE 3	TYPE 4[b]
2000	6.2	15.2	11.9
1500	8.8	19.1	16.4
1000	10.6, 9.7	22.7	21.8, 27.7
750	11.6, 13.7	30.7	22.9
500	12.5	31.4	30.7, 30.8
250	17.5, 16.8	52.5	39.3, 38.8
125	20.0	--	—
100	24.6, 21.2	62.0	41.5
50	25.0	77.0	64.5

[a]Test conditions were 40 liters/min, 50% relative humidity at 20°C. Cartridges were tested as received with no special preconditioning.

[b]Each cartridge pair contained approximately 80 g of petroleum base activated carbon. The average cartridge diameter and bed depth are 6.7 and 2.3 cm, respectively.

TABLE 22

As could be expected, the breakthrough time decreases with increasing contaminant concentration. Although the relationship of concentration and breakthrough time was studied on vinyl chloride it can be extended for other organic compounds. since the mechanism of physical adsorption on activated charcoal is similar for most organic compounds with variations of the rates and limits of adsorption and desorption [89, 90]. Since the concentrations of challenging agents used in respiratory face fit testing are low, the breakthrough should not present a problem.

General Considerations

A definite variation exists between batches of charcoal [83] and therefore between cartridges and canisters. Certain variation can also be expected between canisters produced by different manufacturers, although the differences should not play a significant role in testing the face fit under normal circumstances. When, however, high protection factors are sought (10^{-6} and higher) the penetration of the challenging agent due to channelling and other phenomena must be considered and established.

Halon 1301

Thompson and Eaton [91] carried out experiments in order to determine the maximum capacity for adsorption of Halon 1301 onto charcoal under equilibrium conditions. The results of the experiments are plotted in Figure 12 for pressures from near zero to 1 atm. Curve B is the first part of curve A, up to 50 mm Hg pressure. The adsorption at 760 mm Hg is 65 cc of Halon/gram (0.02/1, w/w) charcoal.

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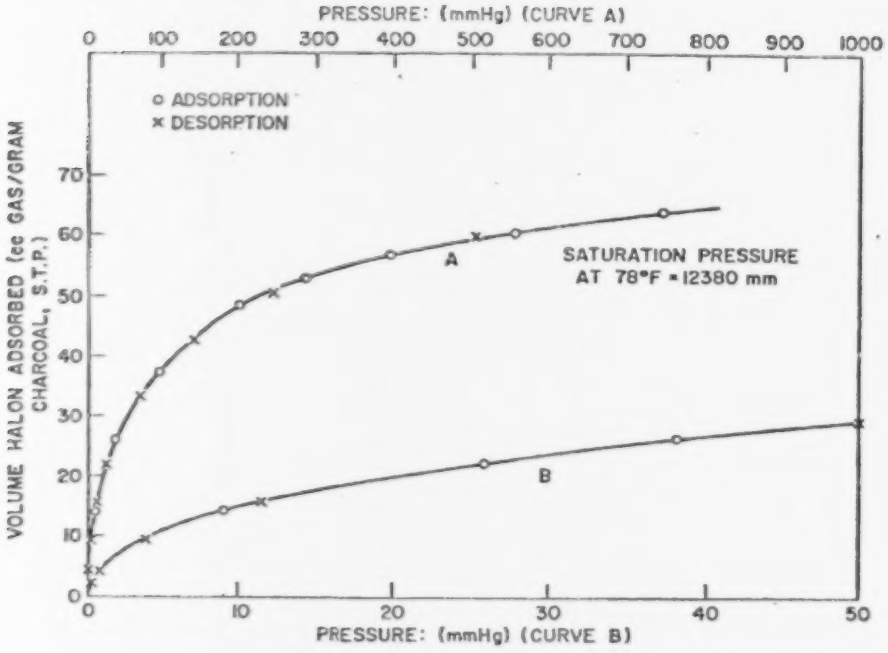

Sorption of Halon 1301 on submarine charcoal at 25.5°C (~ 78°F) (trifluorobromomethane).

FIGURE 12: Sorption of Halon 1301 on charcoal at 25.5°C

It can also be noted that the points for adsorption and desorption fall on the same curve, i.e. there is no hysteresis, showing no measureable irreversible reaction of the Halon with the carbon.

Curve B in Figure 13 shows the result of passing air containing 1 percent (10,000 ppm) of halon 1301 through a few (10) cm charcoal bed at 100 cm/n^2 [91]. The breakthrough occurs at approximately 30 min. It should be noted that the challenging concentration is high (approx. 10-100X) in comparison with that normally used during respirator face fit testing.

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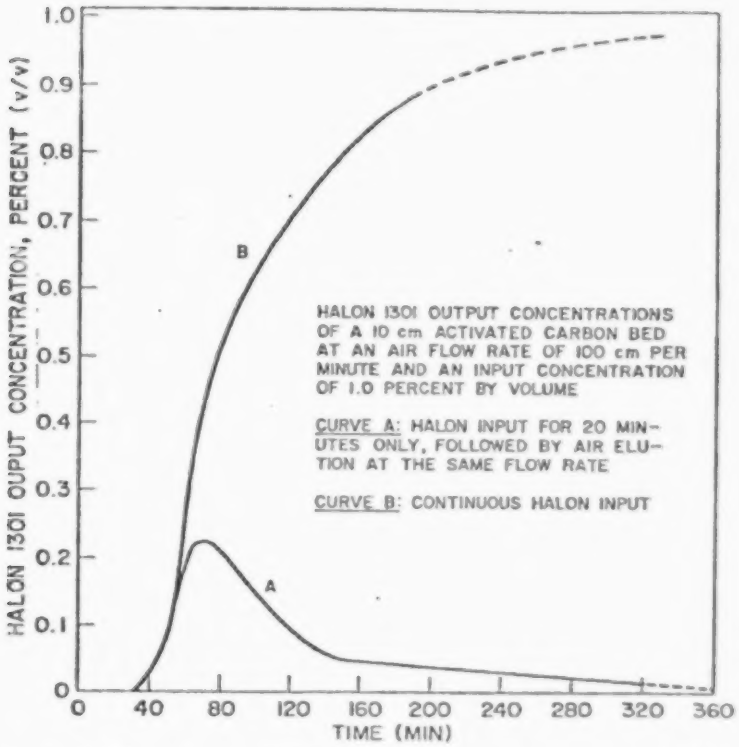

Halon 1301 output concentration, percent (v/v).

FIGURE 13

Additional data on adsorption of Halon 1301 are tabulated in Table 23.

Sulphur hexafluoride (SF_6)

Adsorption of SF_6 on activated charcoal was studied by Fuller et al. [92] by forming sorption isotherms between -83°C and 100°C in the pressure range of 0.13 umPa to 100 kPa (by microgravimetri SF_6 per gram of charcoal were observed. The SF_6 loading isotherms are shown in Figures 14 and Table 24.

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TABLE 23

Adsorption of Halon 1301 on Activated Charcoal
Scale-up of Data

Air Flow Rate, cm./min.	Halon Con. in Air, percent	Break Time min. (10% of input)	Halon on Char at Break cc/g. of char	Halon on 500 lbs. char at Break, lbs.
100	1.0	48	10	33
1000	1.0	2.6	5	16.5
2860	1.0	-	-	~10*

*10 lbs. Halon 1301 vapor = 38 cu. ft. at 25°C; volume at 4% vapor conc. = 950 cu. ft.

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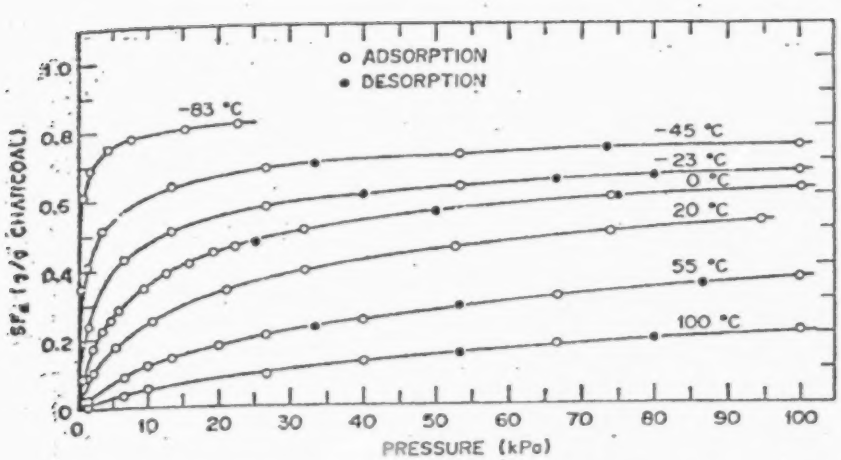

SF_6 loading isotherms on activated charcoal.

FIGURE 14

Properties of SF_6 and Activated Charcoal

temp, °C	vapor pressure (P_0),[a] kPa	liquid SF_6 density,[a] g/cm³	Γ_0, (g of SF_6)/(g of C)	micropore vol, cm³/(g of C)
−83	25	2.00	0.79	0.40
−45	285	1.82	0.76	0.42
−23	625	1.71	0.73	0.43
0	1260	1.56	0.76	0.49
20	2130	1.39	0.76	0.55

TABLE 24

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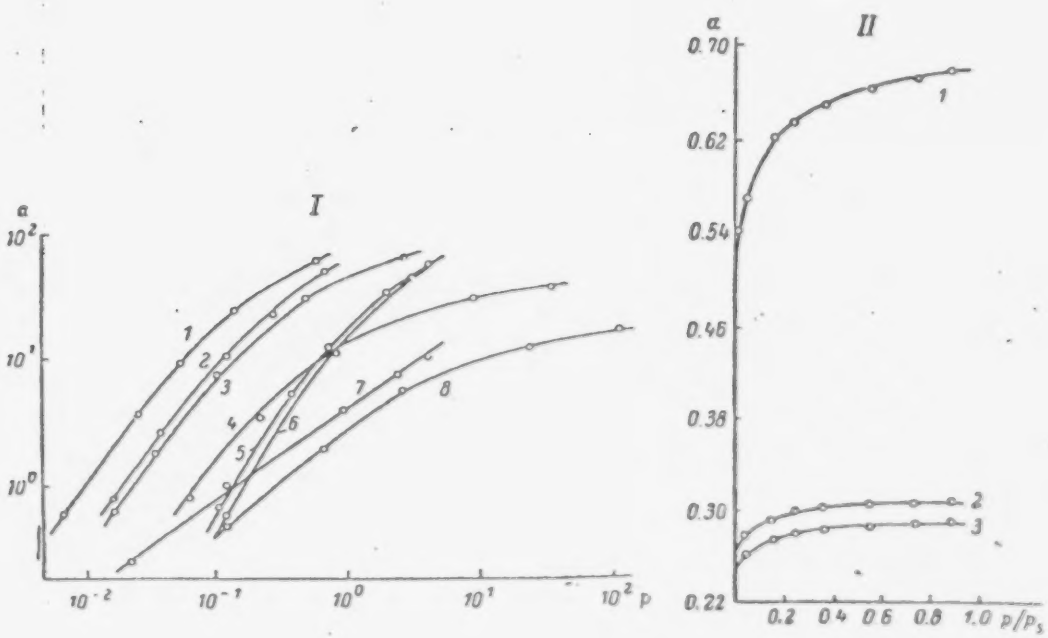
Freon 12 (Difluorochloromethane)

Skazyvayev et al. [93] studied the absorption of certain fluorocarbons including Freon 12 on charcoal. Thus, it was found that 151 mg Freon 12/gm charcoal was absorbed at room temperature. Loading isotherms are shown in Figure 15.



Isotherms of Freon-12
a-adsorption: I-(normal) cm^3/gm; II- cm^3/gm;
p-pressure of Freon-12 (Pa), p/ps - relative pressure

Adsorbents: No. 7 - active charcoal

FIGURE 15

Freon 116 and C-318

Unpublished data have been solicited from duPont de Nemours Ltd. officials who have conducted extensive tests on the absorption of various Freons on charcoal. This important data will be made available as soon as we receive it. All efforts to find charcoal absorption data for these two potential agents have been fruitless to date.

Halothane, Enflurane
Isoflurane, Cyclopropane

The study of anesthetic gases done by Kim and Sircar [94] show that activated carbon is adequate for efficient and economic removal of dilute anesthetics. The Figure 16 shows the experimental equilibrium isotherms plotted as the amount adsorbed in standard cubic centimeters per gram of the carbon, r (scc/g), as a function of the equilibrium partial pressure, P (Torr), of the gas/vapour. The figure shows that the carbon offers very large capacities for the anesthetic vapours even at a very low partial pressure. Maggs and Smith [95] arrived at similar conclusions after testing four types of activated charcoal. Their results indicate high adsorption of anesthetics on activated charcoal, approximately between 30-50 ul (expressed as liquid) per 100 g of charcoal, before penetration occurs. Four anesthetics were tested: Halothane, Methoxyflurane, Trichloroethylene and Chloroform. The results of these tests are shown in Table 25.

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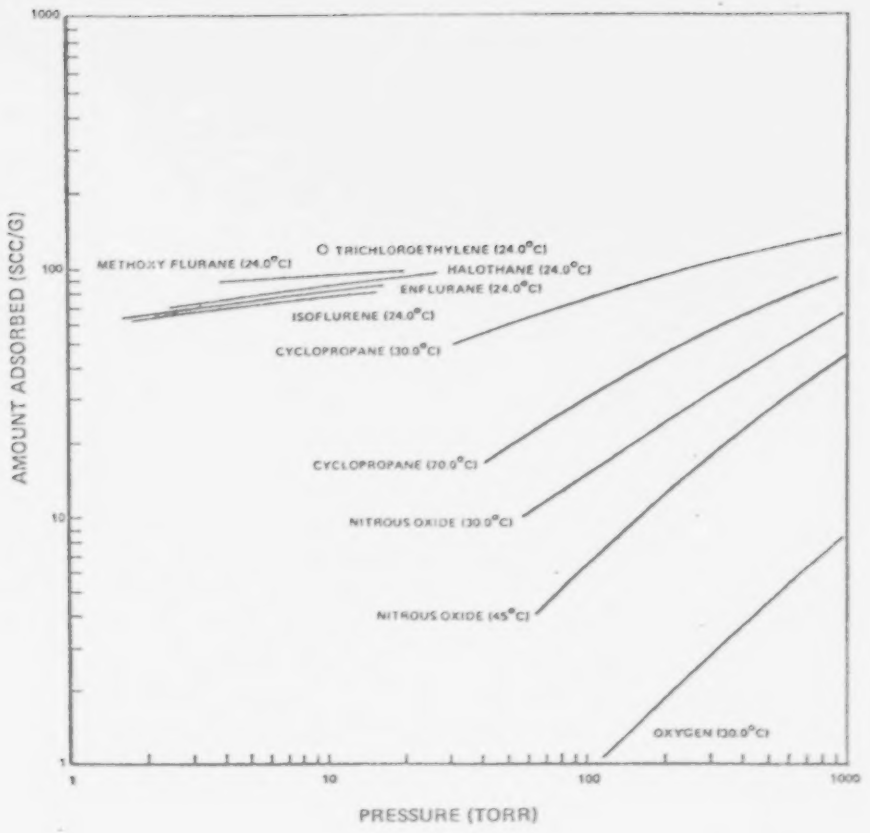

FIGURE 16: Adsorption isotherms for various anesthetics plotted as a function of equilibrium partial pressure of the anesthetic on Witcarb 965 activated charcoal.

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Comparison of charcoals

Test vapour concentration:			Halothane 100 mg/l (1·34% v/v)		Methoxy-flurane 64 mg/l (0·94% v/v)		Trichloro-ethylene 49·6 mg/l (0·91% v/v)		Chloroform 44 mg/l (0·88% v/v)	
Charcoal	Test conditions		PT	W%	PT	W%	PT	W%	PT	W%
	Charcoal	Air								
A	Dry	Dry	150	68	184	48	248	50	242	43
A	Dry	80%	143	67	164	43	197	41	218	39
A	80%	80%	40	18	129	34	145	29	75	13
B	Dry	Dry	151	83	237	76	299	74	274	60
B	Dry	80%	131	73	250	80	270	67	259	56
B	80%	80%	45	25	208	66	217	53	92	20
C	Dry	Dry	92	46	181	53	197	44	171	34
C	Dry	80%	77	38	158	46	188	37	150	30
C	80%	80%	29	20	129	37	105	24	62	12
D	Dry	Dry	99	47	166	45	210	44	172	32
D	Dry	80%	99	47	172	47	206	44	178	33
D	80%	80%	43	20	162	44	161	34	89	16

All tests carried out on 200 ml charcoal at a flow rate of 4 litres/minute.

TABLE 25: Adsorption of anesthetics on activated charcoal

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MEASUREMENT OF CHALLENGING GASEOUS AGENTS IN AIR

As mentioned earlier, to be of any use for the QNFT test, the gaseous challenge agent selected must be readily measureable in air at concentrations less than 100 ppt using unsophisticated analytical instrumentation. This objective can be achieved through the analysis of certain halocarbons or halogen inorganic compounds with a gas chromatograph equipped with an electron capture detector.

It is common knowledge that sulphur hexafluoride can be readily measured at the 1 ppt level in air by direct gas chromatography of air samples. In fact, several portable gas chromatographs are commercially available (e.g. Analytical Instrument Division [AID], S-Cubed) which reportedly can measure this gas at the 1 ppt level. There are few interferences with this analysis and it is specific for SF_6.

Simmonds et al. [96] have suggested the use of a modified electron capture detector for the continuous and extrasensitive monitoring of tracer gases such as SF_6 and perfluorocarbons (e.g. Freon 116 and C-318) using ambient air as the carrier gas. Essentially, the air sample is passed through a simple catalytic reactor that converts interfering atmospheric oxygen and other hydrogenated Freons to water and elemental hydrides respectively. The modified electron capture detector provides a continuous signal in real time over the concentration range of 1 ppb to 0.01 ppt for SF_6 and perfluorocarbons such as Freon 116 and C-318. Freon 12 and, most likely, Halon 1301 and halothane would not be analyseable by this technique. This approach affords a certain specificity to

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the analysis.

Lasa [97, 98] have reported the measurement of Freon 12 used as an atmospheric tracer gas at the 0.2 ppt level using a coulometric electron capture detector. Harsh [99] achieved the analysis of this agent at the 0.8 ppt level only after cryogenically freezing out the compound from a 500-mL air sample.

Orlowski and Senczuk (100) have measured 9.6-48 ug of Halon 1301 in 2-10 ml air samples with an accuracy of $\pm$ 5% using a gas chromatograph equipped with an ECD detector.

No information could be found concerning the attainable detection limits for the measurement of halothane in air using a gas chromatograph equipped with an electron capture detector. However, our present experience with measurement of this agent using this method leads us to believe that it could possibly be analysed at the 100 ppt level in air. This fact would have to be verified experimentally.

Other Considerations

Physico-chemical properties, flammabillity, stability, availability, ease of preparing test atmospheres and background concentrations were all mentioned in the selection criteria portion of this document as being essential to the choice of the best challenge gaseous agent for the QNFT test. These will be briefly considered here.

Firstly, all the candidate compounds selected for study are non-flammable, inherently stable over long periods of storage, commercially available at high purity at reasonable cost (SF_6 is

relatively more expensive), and all lend themselves readily to the preparation of test atmospheres through the use of either permeation tubes [101] or diffusion tubes. All of the candidates, except halothane, are gases at room temperature. Finally, background concentrations for all candidates are < 1 ppt.

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DISCUSSION

A QNFT test involving the use of a gaseous challenging agent could conceivably require an atmosphere of the test substance of 1% (10,000 ppm) or less. Based on this requirement, all of the candidate gases selected for study, except one, halothane, could be safely used for the test since no serious health effects would follow an accidental acute exposure to any one of them. Halothane, on the other hand, is known to produce "halothane hepatitis" in susceptible individuals following anesthesia (induced with 1.5% or less of this anesthetic) and would be risky to use. Furthermore, none of the five remaining agents are known to have any chronic health effects following long-term exposure to low concentrations, whereas halothane has many (Table 26). However, the information at present on this aspect is rather limited for some of these candidate gases.

An attempt has been made to classify the five candidate gases remaining in order of decreasing/acute toxicity in Table 26. According to this ranking, Freon 12 > Halon 1301 > Freon-116, Freon C-318 and SF_6. Hence, based on available toxicity data, either Freon-116, Freon C-318 or SF_6 would appear to be the least toxic of the five gases. However, their preferential ranking could be due to the fact that their toxic properties have not been as extensively investigated to date as those of Halon 1301 or Freon-12. Therefore, despite the fact that it is known to produce cardiac arrhythmia following exposure to atmospheres containing 7% (70,000 ppm), Halon 1301 would be the agent of choice for the QNFT test based on known toxic properties, the extent of the toxicity

TABLE 26

COMPARATIVE CHRONIC AND ACUTE TOXICITY OF
SIX POTENTIAL QNFT TEST CHALLENGING AGENTS
(Listed in order of decreasing chronic/acute toxicity)

Agents	Known Acute Physiological Effect(s)	Known Chronic Physiological Effect(s)	Extent of Toxicity Studies Conducted to Date
HALOTHANE	"Halothane Hepatitis"	- Spontaneous abortion (humans) - Fetal Abnormalities, Malformations (humans) - Malignancies (humans) - Liver Disease (humans) - Reproductive Failure (humans)	Very extensive
FREON-12	ALC >800,000 ppm Moderate Cardiac Sensitization (humans) 7% reduction of standardized psychrometer test at 10,000 ppm (humans)	- none observed	extensive
HALON 1301	ALC -832,000 ppm (animals) Potential cardiac sensitization at 7% (humans) Increased pulse rate at 15% (humans)	None reported to date	Very extensive

TABLE 26

COMPARATIVE CHRONIC AND ACUTE TOXICITY OF
SIX POTENTIAL QNFT TEST CHALLENGING AGENTS
(Listed in order of decreasing chronic/acute toxicity)

Agents	Known Acute Physiological Effect(s)	Known Chronic Physiological Effect(s)	Extent of Toxicity Studies Conducted to Date
	CNS/behavioural effects at concentrations up to 7% (humans) Anesthesia at 10% (humans)		
SULPHUR HEXA-FLUORIDE	ALC >790,000 ppm None reported	None reported	Limited
FREON C-318	ALC >800,000 ppm Increased pulmonary resistance	None reported	Very Limited
FREON-116	Least active cardiac sensitizer amongst Freons	None reported	Very Limited

studies conducted to date and the requirements of the test (test atmosphere $\leq$ 10,000 ppm).

The main route of absorption into the human body for the six agents is uncontestably the inhalation route. Little is known, to date, about the potential absorption by the occular or dermal route. Since this would have serious implications for a QNFT test using such gases, because of the possible exhalation of dermally absorbed gas, the extent of the skin absorption of the gas selected for the QNFT test will have to be determined.

The nature and toxicity of the thermal degradation products of only two of the challenging agents selected for study have been extensively investigated namely, Halon 1301 and sulphur hexafluoride. Both these gases are thermally degradeable to very toxic products. Halon 1301 gives off mainly hydrogen fluoride, hydrogen bromide and bromine, while sulphur hexafluoride releases principally the very toxic sulphur tetrafluoride. Although less is known about the thermal decomposition of the remaining four gases, it could be expected that both halothane and Freon-12 will give off hydrogen fluoride and other hydrohalides or halogen(s). The two perfluorocarbons could likewise give off hydrogen fluoride during thermal decomposition. Thus, all six selected agents can generate toxic products during thermal degradation and precautions must be taken to ensure that this eventuality does not occur during a QNFT test which uses these gases.

All six agents under study are presently in extensive use commercially and, as such, they are readily available at high purity (99.9+%) at reasonable cost.

Its acceptable toxic and other properties notwithstanding, it is obvious that the gaseous agent(s) selected for the QNFT test must not penetrate the charcoal bed in the respirator's cannister during the test. The extent to which each of the six gaseous agent is adsorbed on charcoal and their breakthrough are presented in Table 27 in order of decreasing adsorption.

TABLE 27

ADSORPTION OF GASEOUS CHALLENGING AGENTS ON ACTIVATED CHARCOAL
(in order of decreasing adsorption)

Agent	Adsorption on charcoal (mg/c)	Breakthrough (1% atmosphere)	Extent of Adsorptivity Studies Conducted To Date
HALOTHANE	> 800	--	Fairly Extensive
SULPHUR HEXAFLUORIDE	800	--	Fairly Extensive
FREON-12	151	--	Limited
HALON 1301	20	30 minutes through 10 cm charcoal bed at 100 cm/M^2	Extensive
FREON-116 AND FREON C-318	--DATA NOT AVAILABLE--		

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According to the data presented in Table 27, it is anticipated that the charcoal bed in a typical respirator would adsorb all of the Halothane, SF_6, Freon or Halon 1301 present in a 1% vol/vol (10,000 ppm) atmosphere during a test period of 30 minutes or more. However, with either halothane or sulphur hexafluoride, QNFT tests could be conducted at higher concentrations and for relatively longer periods. It is not possible at this time to provide data on the adsorption of either Freon 116 or C-318 on activated charcoal.

Table 28 summarizes the measurement of gaseous agents in air in order of ease of measurement.

TABLE 28

MEASUREMENT OF POTENTIAL QNFT CHALLENGING AGENTS IN AIR
(listed in order of ease of measurement)

Agent	Analytical Method	Detection in Air (ppt)	Extent of Measuremen Studies Conducted
SULPHUR HEXAFLUORIDE	Gas Chromatograph equipped with electron capture detector (ECD)	1	Extensive
	Gas chromatograph equipped with catalytic reactor	0.01	Single Reference
FREON-116 AND FREON C-318	Gas chromatograph equipped with catalytic reactor	0.01 possible	Required Verification
FREON-12	Gas chromatograph equipped with coulometric ECD	0.2	Limited
HALON 1301	Gas chromatograph equipped with an ECD	< 100 ppt	Requires Verification
HALOTHANE	Gas chromatograph equipped with ECD	< 100 ppt	Requires Verificatior

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According to the data presented in Table 28, sulphur hexafluoride would appear to be the most readily and specifically analysed gaseous agent. It is also possible that both Freon 116 and C-318 would prove as analyseable after limited testing in the laboratory. All three remaining gaseous challenging agents could conceivably be measured at levels <100 ppt albeit less specifically. Furthermore, both Halon 1301 and halothane would require further testing to confirm their detectability at this concentration in air.

As discussed earlier on, all six of the agents selected for study have physico-chemical properties compatible for the conduct of QNFT tests, are readily amenable to the generation of test atmospheres and their natural background concentration is < 1 ppt.

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CONCLUSIVE ASSESSMENT OF CANDIDATE CHALLENGE GASEOUS AGENTS

The six gaseous challenging agents are tentatively ranked as to their overall acceptability for the QNFT test in Table 29.

TABLE 29

RANKING OF THE SIX POTENTIAL GASEOUS CHALLENGING AGENTS AS TO OVERALL ACCEPTABILITY FOR THE QNFT TEST (ranked in order of decreasing acceptability)

Agent	Acute/chronic Toxicity	Adsorptivity on Activated Charcoal	Detectability in Air
SULPHUR HEXAFLUORIDE	1	2	1
HALON 1301 -5%	4	4	2
FREON-12	5	3	3
HALOTHANE	6	1	-
FREON-116 -7%	2	-	-
FREON C-318	3	-	-

Thus, sulphur hexafluoride would appear to be the gaseous agent of choice for conducting QNFT tests since it meets all the criteria set earlier on for such a test gas. Its single drawback would be a certain tendency to adhere to certain materials, for example Teflon. This fact was not mentioned earlier, since it emanates from personal experience with this gas and no data could be found in the literature. Therefore, the adherence of SF_6 to the

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materials used to construct the test chamber and the respirator and associate equipment will have to be tested.

Halon 1301, although a distant second, would also be eminently acceptable as a test gas. However, its adsorption by activated charcoal during the test period and its detectability in air remain to be tested.

Freon-12 could also serve as a challenging agent for QNFT tests. In fact, its adsorption by charcoal is well documented as is its detectability in air. However, it is more toxic than Halon 1301 and, for this reason, is ranked third.

Halothane has known acute and chronic toxic effects and its detectability in air remains to be determined with certainty; for these reasons it is not recommended as a challenge gas and ranked fourth.

Both Freon-116 and Freon C-318 are very promising as potential challenging agents. However, information as to their individual acute/chronic toxicity, adsorption on charcoal, detectability in air and other pertinent data are not available to date and for these reasons they are not recommended as challenging agents for the QNFT test.

RECOMMENDATIONS

1. We recommend that DREO consider using sulphur hexafluoride (SF_6) as a challenge agent for their QNFT tests because it meets all the criteria for such tests.

2. If DREO opts to use SF_6 as its challenge gas, we further recommend that they assess this gas' tendency to adhere to certain material and, more specifically, the material used to construct the testchamber, the respirator and any other material used for the QNFT tests which may come in contact with the gas. Its dermal absorption should also be verified.

3. DREO could also consider using Halon 1301 as a second choice for a challenging agent for the QNFT tests. If such is the case, we further recommend that this gas' dermal absorptivity, charcoal adsorption and detection limit in air be verified.

4. In the event that DREO considers Freon-12 as its QNFT test agent, we recommend that its acute toxic properties and, in particular, its cardiac sensitization be examined more closely. Its dermal absorption would also have to be verified.

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